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Compact lighting system and display device

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Compact lighting system and display device

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The invention relates to a lighting system provided with a light-emitting panel comprising

- a front wall, a rear wall situated opposite thereto, and furthermore, between the front and the rear wall, a translucent in-coupling edge surface for coupling light into the light-emitting panel,

- while at least a light source is associated with the in-coupling edge surface, and

- while, in operation, light originating from the light source is incident on the in-coupling edge surface and distributes itself in the light-emitting panel.

The invention also relates to a display device provided with said lighting system.

Such lighting systems are known per se and are also denoted edge lighting systems. They are used inter alia as backlighting systems in (picture) display devices, for example for TV sets and monitors. Such lighting systems are particularly suitable for use as backlights for non-emissive displays such as liquid crystal display devices, also denoted LCD panels, which are used in (portable) computers or (portable) telephones.

Said display devices usually comprise a substrate provided with a regular pattern of pixels which are each controlled by at least one electrode. The display device utilizes a control circuit for achieving a picture or a data graphical display in a relevant field of a (picture) screen of the (picture) display device. The light originating from the backlight in an LCD device is modulated by means of a switch or modulator, various types of liquid crystal effects being used. In addition, the display may be based on electrophoretic or electromechanical effects.

Such lighting systems are also used as luminaires for general lighting purposes or for shop lighting, for example shop window lighting or lighting of (transparent or semi-transparent) plates of glass or of synthetic resin on which items, for example jewelry, are displayed. Such lighting systems are further used as window panes, for example for causing a glass wall to radiate light under certain conditions, or to reduce or block out the view

through the window by means of light. A further alternative application is the use of such lighting systems for illuminating advertising boards.

In the lighting systems mentioned in the opening paragraph, the light source used is usually a tubular low-pressure mercury vapor discharge lamp, for example one or a plurality of cold-cathode fluorescent lamps (CCFL), wherein the light emitted by the light source during operation is coupled into the light-emitting panel, which acts as an optical waveguide. This waveguide usually constitutes a comparatively thin and planar panel which is manufactured, for example, from synthetic resin or glass, and in which light is transported through the optical waveguide under the influence of (total) internal reflection.

As an alternative light source, such a lighting system may also be provided with a plurality of optoelectronic elements, also referred to as electro-optical elements, for example electroluminescent elements, for example light-emitting diodes (LEDs). These light sources are usually provided in the vicinity of or tangent to a light-transmitting edge surface of the light-emitting panel, in which case light originating from the light source is incident on the light-transmitting edge surface during operation and distributes itself in the panel.

A lighting system is known from US-A 5,575,549. Light from a linear light source with a uniform brightness is coupled into a light-emitting panel, also denoted as a light pipe, via a light incident edge surface. Part of the light transmitted through said light incident edge surface is made incident upon inclined surfaces of conical or polygonal pyramid-shaped so-called concave portions. Light is coupled out from the light-emitting panel after the light has been refracted at the concave portions in the light conducting member.

A drawback of the known lighting system is that the uniformity distribution of the light coupled out from the light-emitting panel still is relatively poor.

It is an object of the invention to eliminate the above disadvantage wholly or partly. According to the invention, a lighting system of the kind mentioned in the opening paragraph is for this purpose characterized in that the rear wall in a first portion of the light-emitting panel is provided with a multiplicity of steps, and in that a second portion of the light-emitting panel widens from the in-coupling edge surface in a direction facing the first portion.

Since the second portion of the light-emitting panel widens from the in-coupling edge surface towards the first portion, the light coupled into the light-emitting panel at the in-coupling edge surface cannot leave the light-emitting panel during its first travel through the light-emitting panel from the in-coupling edge surface towards the first portion.

- 5 The angular light distribution of light traveling through such a wedge-shaped second portion of the light-emitting panel becomes gradually narrower. Generally speaking, light is collimated in a light-emitting panel which widens. In a light-emitting panel based on total internal reflection (TIR), light not exceeding a limit angle can not be coupled out from a light-emitting panel. In the reverse situation, in which light travels through a light-emitting
- 10 panel which narrows, the angular light distribution becomes gradually greater. Since the light coupled into the light-emitting panel at the in-coupling edge surface during its first travel through the second portion of the light-emitting panel cannot leave this second portion of light-emitting panel, it is promoted that the light during this travel through the second portion of the light-emitting panel distributes itself in the light-emitting panel, and also that
- 15 the light, if originating from two or more, possibly differently colored light sources, is satisfactorily mixed. A good distribution and/or mixing of light promotes the uniformity of the light issued from the light-emitting panel. The second portion of the light-emitting panel acts as if it were a light-mixing chamber for light on its first path through a widening second portion of the light-emitting panel. Such a "light-mixing chamber" is usually provided
- 20 outside the light-emitting panel in known lighting systems, which is why such light-emitting panels occupy unnecessarily much space. By employing a light-emitting panel with a wedge-shaped second portion according to the invention, the "light-mixing chamber" is integrated into the light-emitting panel leading to a considerable saving in space.

- It is noted that wedge-shaped light-emitting panels are known per se (see, e.g.
- 25 the lighting system known from US-A 5,575,549), but such known wedge-shaped light-emitting panels are widest at the area of the edge surface where light is coupled into the light-emitting panel and narrowest at the opposite end of light-emitting panel.

- Normally, the second portion would end in a reflecting edge surface at the side of the light-emitting panel facing the in-coupling edge surface. After reflection the angular
- 30 light distribution increases again, in dependence on the manner in which the reflection takes place. On its return path through such a light-emitting panel, light will have a further increasing angular distribution owing to the fact that the light-emitting panel gradually narrows. At a certain moment the angular light distribution will have become so wide that part of it exceeds the limit angle for total internal reflection, and light will issue from the

light-emitting panel. Normally, the light at reflection is given a tilt such to promote the out-coupling of light on its way back in the direction of the in-coupling edge surface. However, such a tilt given to the reflected light should be such that the light is coupled out over the whole area of the front wall of the light-emitting panel to uniformly illuminate the display device. Under said reflection conditions a bright band of light is issued from the front wall of the light-emitting panel in the vicinity of said reflecting edge surface. The brightness of said band of light is substantially higher than the light emitted at the rest of the front wall of the light-emitting panel. A solution would be to exclude this bright band of light from the light contributing to illuminating the display device. However such shielding is space consuming and the system efficiency would be reduced.

The inventors have had the insight that the above-described bright band of light originated from light coupled out directly after reflection at the reflecting edge surface. The light coupled out at the bright band of light is practically the sum of all light coupled in with solid angles bigger than a limit angle, for which the angle after reflection at the reflecting edge surface is equal to the critical angle for TIR. According to the measure of the invention the rear wall in the first portion of the light-emitting panel is provided with a multiplicity of steps. As a consequence, the bright band of light is split in many shorter bright bands of light which are spread over the front wall of the light-emitting panel. The spatial frequency of the steps in the first portion of the light-emitting panel can be chosen such that the brightness modulation from the many small bands of light can no longer be resolved, the brightness is averaged and appears homogeneous. The averaged, i.e. lower brightness of the bright band of light can be tuned equally high to the brightness of the remaining of the front wall.

A particularly compact lighting system is obtained through the measure according to the invention, with a high uniformity of the distribution of the light emitted by the lighting system. A more uniform illumination of the display device is realized thereby in particular in the case of (picture) display devices.

A preferred embodiment of the lighting system according to the invention is characterized in that a surface of the steps facing the in-coupling edge surface makes an angle β with respect to a normal on a bisecting plane bisecting the light-emitting panel, wherein the bisecting plane comprises a bisecting line in the in-coupling edge surface, said bisecting line being parallel to the front wall and bisecting the in-coupling edge surface, and wherein the angle β is at least 5° .

The bisecting plane makes an angle with the front wall of the light-emitting panel and divides the second portion of the light-emitting panel in half. The angle β is responsible for the rotation of the angular intensity distribution of the returning light such that the light on its way back is extracted over the entire length of the second portion of the light guide. Depending on the ratio of the surface area S_{es} of the in-coupling edge surface and the largest surface area S_{lr} in the light-emitting panel, the form of the surface of the steps can be chosen flat for ratios $S_{lr}/S_{es} \leq 2.5$. Otherwise, the angle β must be varied to ensure a widening of the angular intensity distribution, and the form of the step surfaces will be preferably curved. In the following, values for the average value of β , β_{av} , will be discussed.

Preferably, the angle β_{av} is in the range from $5 \leq \beta \leq 25^\circ$. Two different of embodiments of the light guide ending and reflecting surface can be distinguished. One embodiment includes an air gap between light guide ending and (diffuse) reflecting surface. In this case, $\beta_{av} > 5^\circ$ for a light guide material with refraction index $n \approx 1.5$ to ensure that light extraction starts in the beginning of the second portion of the light guide, where with "beginning" it is meant the side opposite to the in-coupling edge surface of the panel. Equally, β_{av} must not be too large, to ensure that light is still extracted close to the in-coupling edge surface. Simulations have shown that values $\beta_{av} > 25^\circ$ are disadvantageous. This originates from the fact that the portion of light that after reflection is outside the regime of total internal reflection increases with increased values of β . Of course this also relates to the angular distribution of the light at coupling into the light guide. A smaller angular distribution at this stage makes larger values of β possible and/or necessary, but to obtain this narrower distribution a larger thickness of the light guide at the in-coupling edge is required, which again is disadvantageous.

A preferred embodiment of the lighting system according to the invention is characterized in that the surface of the steps facing the in-coupling edge surface comprises a specular reflector at a side facing away from the in-coupling edge surface. Such a specular reflector provides the desired reflection of the light traveling from the in-coupling edge surface and stimulates the coupling of light out of the light-emitting panel.

In an alternative embodiment, the steps comprise a diffuser at a side facing away from the light-emitting panel while maintaining an air gap between the steps and the diffuser or at least preventing optical contact between the light guide and the diffuse reflector. Preferably, the diffuser is made from a diffuse, highly reflecting material copying the shape of the steps of the first portion of the light-emitting panel. In the diffuse case the

thickness of the air gap between light-emitting panel and the diffuser should be carefully controlled. Preferably, the diffuse material has a very short penetration depth ($< 0.1\text{ mm}$). The advantage of employing a diffuser is the very high robustness against light source radiation pattern and in-coupling geometries.

5 A preferred embodiment of the lighting system according to the invention is characterized in that the ratio of the surface area S_{es} of the in-coupling edge surface and the surface area S_{tr} in the light-emitting panel at the transition between the first portion and the second portion of the light-emitting panel satisfies the relation $1 < S_{tr}/S_{es} < 10$. Light
10 originating from the light source and coupled into the second portion of a light-emitting panel has an angular distribution which varies between approximately $+42^\circ$ and -42° , for typical light guide materials with a refractive index of approximately 1.5. The lower limit for the ratio of the cross section S_{tr} at the transition between the first and the second portion, where the light-emitting panel is at the largest thickness and the surface area S_{es} of the in-coupling edge surface, is given by the fact that the light-emitting panel is wedge-shaped in the second
15 portion of the light-emitting panel. The upper limit for the ratio $S_{tr}/S_{es} < 10$ is determined by the wish that the light-emitting panel should not become too thick. In principle, the dimensions (screen diameter) of, for example, the display device determines the size (diameter) of the light-emitting panel. If the in-coupling edge surface has a thickness of 2 mm, then the equation $S_{tr}/S_{es} = 10$ means that either the second edge surfaced or the cross-
20 section of the light-emitting panel parallel to the in-coupling edge surface at the largest thickness of the light-emitting panel will have a thickness of 20 mm. The ease of manufacture of the light-emitting panel is also reduced in the case of such high ratios.

Preferably, the ratio S_{tr}/S_{es} satisfies the relation $1.5 < S_{tr}/S_{es} < 4$. Light-emitting panels with a S_{tr}/S_{es} ratio in the preferred range can be readily manufactured in an
25 (injection) molding process.

The light source used may be formed by LEDs, for example white LEDs or different types of LEDs and/or LEDs of different colors which are combined with one another. Colors may be mixed in a desired manner through a suitable use of LEDs, for example for making white light of a desired color temperature. For this purpose, an
30 embodiment of the lighting system according to the invention is characterized in that the light source comprises one white LED or at least two light-emitting diodes with different light emission wavelengths. Preferably, the light source comprises three light-emitting diodes. Employing a single white LED is advantageous because the widening portion of the light-emitting panel is used for the homogenization of the light distribution in the light-emitting

panel. The LEDs preferably comprise the combinations of red, green, and blue LEDs known per se, or, for example, combinations of red, green, blue, and amber LEDs. LEDs with three light emission wavelengths may also be realized by means of two LEDs with different light emission wavelengths, wherein the LEDs of one of the types are (partly) provided with a phosphor, such that the light emission of the LED is converted by the phosphor into light of a third, desired light emission wavelength. A combination, known per se, of the red, green, and blue LEDs renders it possible to realize color changes independently of the status of the display device. The use of LEDs has the further advantage that dynamic lighting possibilities are obtained. For this purpose, a sensor is present at one of the edge surfaces for measuring the optical properties of the light emitted by the light source during operation.

The quantity of light emitted by the LEDs is adjusted in that the luminous fluxes of the light-emitting diodes are varied. This control of the luminous flux usually takes place in an energy-efficient manner. Thus the LEDs can be dimmed without an appreciable loss in efficacy. Preferably, the intensity of the light emitted by the light-emitting diodes is variable in response to the illumination level of a picture to be displayed by the display device or in response to the level of the ambient light. Preferably, the color point of a picture displayed by the display device is determined by the lighting system. An (improved) dynamic range (for example contrast) of the picture to be displayed by the display device is achieved thereby.

Preferably, each of the light-emitting diodes has a luminous flux of at least 5 lm. Such high values are particularly useful for high brightness large screen applications, i.e. with a value of the quotient of the light emitting panel luminous output and the panel diagonal of more than 10 lm/inch. LEDs with such a relatively high output are also denoted LED power packages. The use of these high-efficiency, high-output LEDs has the specific advantage that the number of LEDs required for a desired, comparatively high light output can be comparatively small. This benefits the compact construction and the efficiency of the lighting system to be manufactured. Further advantages of the use of LEDs are a comparatively very long useful life, the comparatively low energy cost, and the low maintenance cost for a lighting system with LEDs.

A considerable length is available for mixing the various light colors until the desired color mixture has been reached, for example white light of a predetermined color temperature, in a lighting system with a light-emitting panel comprising a wedge-shaped portion widening from the in-coupling edge surface and in which the light cannot be coupled out during its first travel through the widening (second) portion of the light-emitting panel.

Light-emitting panels of comparatively large dimensions can be realized in this manner with a light source which comprises in total, for example, six or even at most three (high-output) light-emitting diodes with different light emission wavelengths. In an alternative embodiment a single LED suffices. In the known lighting system, a light-mixing chamber of considerable dimensions is usually necessary for such a limited number of LEDs in order to achieve that the light is sufficiently distributed and, in case of multiple LEDs, mixed in the light-emitting panel so as to provide a uniform and homogeneous coupling-out of light from the light-emitting panel in the direction of the (picture) display device.

In a further preferred embodiment, the lighting system comprises control electronics for changing the luminous flux of the light source. The desired lighting effects are achieved by means of suitable control electronics, and the uniformity of the emitted light is improved. White light is also obtained through a suitable combination of LEDs, for which the control electronics provide the possibility of adjusting the desired color temperature.

A particularly compact lighting system is obtained through the measure according to the invention, with a high uniformity of the distribution of the light emitted by the lighting system. A more uniform illumination of the display device is realized thereby in particular in the case of (picture) display devices.

The invention will now be explained in more detail with reference to a number of embodiments and a drawing, in which:

Figure 1A is a perspective view of a display device comprising an embodiment of the lighting system according to the invention;

Figure 1B is a cross-sectional view of a detail of the lighting system as shown

in Figure 1A;

Figure 2A shows the light emitted from a wedge-shaped light-emitting panel with a single step which upon reflection at the surface of the step is outside the regime of total internal reflection;

Figure 2B shows the light emitted from a wedge-shaped light-emitting panel which upon reflection at the surface of the steps is outside the regime of total internal reflection in a panel with a number of steps with no distance between the steps, β taking alternatively positive and negative values;

Figure 2C shows the light which upon reflection at the surface of the steps is outside the regime of total internal reflection and subsequently is emitted from a wedge-

shaped light-emitting panel according to the invention with a number of steps which are at a certain distance with respect to each other, and

Figure 3 shows the uniformity distribution of the light emitted by a front wall of a light-emitting panel according to the invention with a single step at various values of the angle β .

The Figures are purely diagrammatic and not drawn true to scale. Some dimensions are particularly strongly exaggerated for reasons of clarity. Equivalent components have been given the same reference numerals as much as possible in the Figures.

Figure 1A shows very schematic a perspective view of a display device comprising an embodiment of the lighting system according to the invention. The lighting system comprises a light-emitting panel 1 of a light-transmitting material. The light-emitting panel 1 is manufactured, for example, from a synthetic resin, from acryl, from polycarbonate, from pmma, for example perspex, or from glass. Light is transported through the light-emitting panel 1 during operation, utilizing total internal reflection (TIR). The light-emitting panel 1 has a front wall 2 and a rear wall 3 opposite thereto. An in-coupling edge surface 4 is provided between the front wall 2 and the rear wall 3 of the light-emitting panel 1. In the example of Figure 1A, the in-coupling edge surface 4 is at an angle between 80 and 100° with respect to the front wall 2 of the light-emitting panel 1. The in-coupling edge surface 4 is light-transmitting. The lighting system comprises a light source 6, 6', ... for example a number of light-emitting diodes (LEDs). In the situation shown in Figure 1, light originating from the light source 6, 6', ... is incident on the in-coupling edge surface 4 of the light-emitting panel 1 during operation, which light distributes itself in the light-emitting panel 1. Reflector means (not shown in Figure 1A) may be provided between the light source 6, 6', ... and the in-coupling edge surface 4 to guide the light of the e.g. LEDs into the light-emitting panel 1. In an alternative embodiment the LEDs are provided inside the light-emitting panel. To this end the light-emitting panel may be provided with an indentation with a shape which is substantially complementary to the shape of the light source. In this case the indentation functions as the in-coupling edge surface. According to the measure of the invention, the rear wall 3 in a first portion 12 of the light-emitting panel 1 is provided with a multiplicity of steps 13, 13', ... (see also Figure 1B). In addition, a second portion 22 of the light-emitting panel 1 widens from the in-coupling edge surface 4.

Light is coupled into the light-emitting panel 1 at the thin end (in-coupling edge surface 4) of second portion 22 of the light-emitting panel 1 and propagates towards the first portion 12 of the light-emitting panel 1. In the example of Figure 1A, light-emitting panel 1 reaches its largest cross section S_{1r} at the transition between the first and second portion. This transition is indicated in Figure 1A by an imaginary plane with reference numeral 122. In the first portion 12, light is reflected at surfaces 17 of the of the steps 13, 13', ..., said surface 17 facing the in-coupling edge surface 4. After reflection, the light can be coupled out from the light-emitting panel 1.

As a rule of thumb, the height h_{st} of a step is preferably in the range $0.1 \leq h_{st} \leq 0.5$ mm, the last step, closest to the front wall, may for mechanical reasons been chosen thicker (e.g. 2 mm), the angle β of that particular step being accordingly lowered. In addition, the distance d_{st} between two steps is in the range $0.1 \leq d_{st} \leq 10$ mm.

The spatial frequency of the steps in the first portion of the light-emitting panel can be chosen such that the brightness modulation from the many small bands of light can no longer be resolved, the brightness is averaged and appears homogeneous. Therefore, a preferred embodiment of the lighting system according to the invention is characterized in that the number of steps is in the range from 25 to 100.

A preferred embodiment of the lighting system according to the invention is characterized in that the length l_{fp} of the first portion as compared to the length l_{fw} of the front wall is in the range $0.05 \leq l_{fp}/l_{fw} \leq 0.6$. By selecting a ratio l_{fp}/l_{fw} in the given range the uniformity distribution of the light coupled out from the light-emitting panel improves further.

Preferably, the ratio of the surface area S_{es} of the in-coupling edge surface 4 and the surface area S_{1r} in the light-emitting panel at the imaginary transition plane 122 between the first portion 12 and the second portion 22 of the light-emitting panel 1 satisfies the relation $1 < S_{1r}/S_{es} < 10$. Particularly preferred is a ratio S_{1r}/S_{es} satisfying the relation $1.5 < S_{1r}/S_{es} < 4$. Light-emitting panels in which the S_{1r}/S_{es} ratio lies within the preferred range can be readily manufactured in an (injection) molding process. A particularly suitable ratio is $S_{1r}/S_{es} \approx 2$. For example, a suitable thickness of the in-coupling edge 4 surface is 3 mm, which means that for $S_{1r}/S_{es} = 2$ the largest thickness of the light-emitting panel 1 is 6 mm. An alternative suitable thickness for the in-coupling edge surface 4 is 1 mm, which means that the largest thickness of the light-emitting panel 1 is 2 mm in the case of $S_{1r}/S_{es} = 2$.

Since the second portion 22 of the light-emitting panel 1 widens from the incoupling edge surface 4, light cannot leave the light-emitting panel 1 during its first travel through the widening second portion 22. It is promoted thereby that the light in its first travel through the second portion 22 of the light-emitting panel 1 distributes itself and is mixed in the light-emitting panel 1. A good distribution and/or mixing of light promotes the uniformity and the homogeneity of the light coupled out from the light-emitting panel 1. The second portion 22 of light-emitting panel 1 such as shown in Figure 1A acts as it were a light-mixing chamber for light during its first travel through a widening light-emitting panel. According to the measure of the invention, the light-mixing chamber is as it were integrated into the light-emitting panel, which leads to a considerable saving in space. A particularly compact lighting system is obtained through the measure according to the invention, with a high uniformity of the distribution of the light emitted by the lighting system.

In Figure 1A, the length l_p of the first portion 12 is indicated as well as the length l_{fw} of the front wall 2. Preferably, the ratio is in the range $0.05 \leq l_p/l_{fw} \leq 0.6$. If, by way of example, the length l_{fw} of the front wall 2 is approximately 300 mm, the length l_p of the first portion 12 is approximately 30 mm, i.e. $l_p/l_{fw} \approx 0.1$. Preferably, the number of steps 13, 13', ... lies in the range from 25 to 100. In the example given ($l_p \approx 30$ mm), a particular advantageous number of steps is 50. Preferably, the height h_{st} of a step 13, 13', ... (see Figure 1B) is in the range $0.1 \leq h_{st} \leq 0.5$ mm. A light-emitting panel 1 with such steps can be easily manufactured.

In the example of Figure 1A, a diffuser is provided behind the steps 13, 13', ... while an air gap 33 is maintained between the steps 13, 13', ... and the diffuser 32. In the example of Figure 1a, the diffuser 32 is a block with a form complementary to the shape of the steps 13, 13', ... of the first portion 12 of the light-emitting panel 1. Preferably, the diffuser 32 is made from a diffuse, highly reflecting material, for instance Teflon, diffuse reflecting aluminum or a coating containing highly reflecting particles as halophosphates, calcium pyrophosphate, strontium pyrophosphate and titanium dioxide or e.g. an expanded polytetrafluoroethylene coating. Such coatings which show a long penetration depth, can be used as thin layer (0.1 mm) combined with a specular reflector layer thereafter to achieve higher reflectivity. Likewise, the white powders could be applied onto the light guide, the approximately spherical grains assuring that there is virtual no optical contact between powder layer and light guide, and a solid specular reflector positioned behind to keep the powder in place. Preferably, the diffuse material has a very short penetration depth (< 0.1 mm). Likewise, the air gap has to be small (< 0.1 mm) and controlled in thickness

over the edge height (preferably ± 0.025 mm). In an alternative embodiment of the lighting system the surface of the steps facing the in-coupling edge surface comprises a specular reflector at a side facing away from the in-coupling edge surface (not shown in Figure 1A).

The light-emitting panel 1, during operation, emits light in the direction of a display device for example a liquid crystal display (LCD) device 20 via a translucent diffuser 8 in order to further homogenize the light issued from the light-emitting panel 1. The assembly of the light source 6, 6', ..., the light-emitting panel 1, and the LCD device 20, whether or not accommodated in a housing (not shown in Figure 1A), forms a display device for displaying, for example, (video)images. The light-emitting panel 1 may further be provided with a sensor (not shown in Figure 1A) for measuring the optical properties of the light. This sensor is coupled to control electronics (not shown in Figure 1A) for suitably adapting the luminous flux of the light source 6, 6', A feedback mechanism can be realized by means of the sensor and the control electronics for influencing the quality and quantity of the light coupled out from the light-emitting panel.

In an alternative embodiment, the front wall 2 is provided with a light redirecting foil.

Preferably, the light source 6, 6', ... comprises one white LED or at least two light-emitting diodes with different light emission wavelengths. Preferably, the light source comprises three light-emitting diodes with a blue, a green, and a red light emission wavelength. The source brightness of a LED is usually many times higher than that of a fluorescent tube. Furthermore, the coupling efficiency of light into the panel with the use of LEDs is greater than with the use of fluorescent tubes. The use of LEDs as a light source has the advantage that the LEDs may lie against panels made from synthetic resin. LEDs transmit hardly any heat in the direction of the light-emitting panel 1, neither do they generate detrimental (UV) radiation. The use of LEDs, in addition, has the advantage that no means need be applied for coupling the light originating from the LEDs into the panel. The LEDs in the lighting system may comprise suitably chosen clusters of blue, green, and red LEDs, or suitable alternative combinations of single-color or dual-color LEDs, or a plurality of white LEDs with high luminous flux.

The LEDs used in a large screen high brightness lighting system, characterized by a value of the quotient of the light emitting panel luminous output and the panel diagonal of more than 10 lm/inch, are preferably LEDs which each have an optical power of at least 50 mW. LEDs with such a high output are also referred to as LED power packages. Examples of power LEDs are LEDs of the "LuxeonTM" type (Lumileds), of which the

luminous flux per LED is 35 lm for red, 30 lm for green, 8 lm for blue, and 40 lm for amber LEDs. In alternative embodiments, yellow, amber, cyan, magenta, and/or purple LEDs are used which have a comparatively high light output (whether or not with the aid of two spectral light emission wavelengths). It is also possible to use a plurality of white LEDs of high luminous flux. In further alternative embodiments, red LEDs may be used in combination with blue LEDs which are provided with a phosphor, such that the latter emit in two spectral bands, i.e. a blue and a green band.

Preferably, the LEDs are mounted on a (metal-core) printed circuit board (not shown in Figure 1A). When power LEDs are provided on such a (metal-core) printed circuit board (PCB), the heat generated by the LEDs can be readily removed by the PCB through thermal conduction. An interesting embodiment of the lighting system is furthermore one in which the (metal-core) printed circuit board is in contact with the housing of the display device via a thermally conducting connection.

Figure 1B shows a cross-sectional view of a detail of the lighting system as shown in Figure 1A. In the first portion 12, a surface 17 of the steps 13, 13', ... facing the in-coupling edge surface 4 makes an angle $\beta \geq 5^\circ$ with respect to a normal 25 on a bisecting plane 20 bisecting the light-emitting panel 1. The bisecting plane 20 makes an angle with the front wall 2 of the light-emitting panel 1 and divides the second portion 22 of the light-emitting panel 1 in half. To this end, the bisecting plane 20 comprises a bisecting line 21 in the in-coupling edge surface 4, said bisecting line 21 being parallel to the front wall 2 and bisecting the in-coupling edge surface 4. Preferably, the angle β_{av} is in the range $5 \leq \beta_{av} \leq 25^\circ$. Particularly preferred is an angle β_{av} of approximately 15° – 19° .

Figure 2A shows very schematically the light in a wedge-shaped light-emitting panel 101 with a front wall 102 and a rear wall 103 and with a single step 113 ("single-facet back reflector"). It can be seen that at the edge of the front wall 102 facing away from the light source (not shown in Figure 2A) a bright band of light is formed. The brightness of said band of light is substantially higher (factor of two or more) than the light emitted at the rest of the front wall 102 of the light-emitting panel 101. A solution would be to exclude this bright band of light from the light contributing to illuminating the display device. However, by making this part of the front wall 102 not "available" is disadvantageous. Such a shielding is space consuming, which is a problem in applications of the light-emitting panel 101 as backlight for display devices, in particular for (laptop) LCD backlighting. In addition, the system efficiency would be reduced (depending on the geometry this may be up to more than 10%) which is particularly important in case of (laptop) display devices.

Figure 2B shows very schematically the light emitted in a wedge-shaped light-emitting panel 201 with a front wall 202 and a rear wall 203 and with a number of steps 213 with no distance between the steps 213 ("multi-facet back reflector"). The situation is improved with respect to the situation in Figure 2A. Multiple bright bands of light are created. However, the bright bands of light occur still relatively close to the edge of the front wall 202 facing away from the light source (not shown in Figure 2B).

Figure 2C shows very schematically the light in a wedge-shaped light-emitting panel 1 with a front wall 2 and a rear wall 3 and according to the invention with a number of steps 13, 13', ... spaced with respect to each other ("stretched multi-facet back reflector") (see also Figure 1A and 1B). The bright bands of light are distributed over a relatively large part of the front wall 2 of the light-emitting panel 1.

Figure 3 shows the uniformity distribution of the light emitted by a front wall 2 of a light-emitting panel 1 according to the invention for a one-step facet at various values of the angle β (see Figures 1A and 1B). The length of the front wall 2 in this example is 250 mm. The ratio of the surface area S_{es} of the in-coupling edge surface 4 and the surface area S_{fr} in the light-emitting panel at the imaginary transition plane 122 between the first portion 12 and the second portion 22 of the light-emitting panel 1 in the example of Figure 3 is $S_{fr}/S_{es} = 2$. The light source is located at the side of the light-emitting panel 1 where $x=0$ mm. For values of the angle $\beta \leq 10^\circ$ it can be seen that too much light is emitted at the beginning of the light-emitting panel 1 (i.e. at $x \leq 100$ mm) resulting in a too low light level emitted by the remainder of the front wall 2 (i.e. at $x > 100$ mm). For values of the angle $22 \leq \beta \leq 15^\circ$ it can be seen that the light distribution is relatively flat but relatively much light is emitted at the end of the light-emitting panel 1 (i.e. at $x > 225$ mm). For values of the angle β of approximately 17° , the stretched multi facet solution of this invention can spread the bright band at the end of the light emitting panel and combine that with a relatively flat light distribution over the entire front wall.

It will be obvious that many modifications are possible to those skilled in the art within the scope of the invention. The scope of protection of the invention is not limited to the embodiments given. The invention resides in each novel characteristic and each combination of characteristics. Reference numerals in the claims do not limit the scope of protection thereof. The use of the verb "comprise" and its declinations does not exclude the presence of elements other than those specified in the claims. The use of the indefinite article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.

CLAIMS:

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(76)

1. A lighting system provided with a light-emitting panel (1) comprising
- a front wall (2), a rear wall (3) situated opposite thereto, and furthermore,
between the front and the rear wall (2, 3), a translucent in-coupling edge surface (4) for
coupling light into the light-emitting panel (1),

5 - while at least a light source (6, 6', ...) is associated with the in-coupling edge
surface (4), and

- while, in operation, light originating from the light source (6, 6', ...) is
incident on the in-coupling edge surface (4) and distributes itself in the light-emitting panel
(1),

10 characterized

in that the rear wall (3) in a first portion (12) of the light-emitting panel (1) is
provided with a multiplicity of steps (13, 13', ...), and

in that a second portion (22) of the light-emitting panel (1) widens from the in-
coupling edge surface (4) in a direction facing the first portion (12).

15

2. A lighting system as claimed in claim 1, characterized in that a surface (17) of
the steps (13, 13', ...) facing the in-coupling edge surface (4) makes an average angle β_{av}
with respect to a normal (25) on a bisecting plane (20) bisecting the light-emitting panel (1),

20 wherein the bisecting plane (20) comprises a bisecting line (21) in the in-
coupling edge surface (4), said bisecting line (21) being parallel to the front wall (2) and
bisecting the in-coupling edge surface (4), and

wherein the angle β_{av} is at least 5° .

3. A lighting system as claimed in claim 1, characterized in that the average
25 angle β is in the range $5 \leq \beta_{av} \leq 25^\circ$.

4. A lighting system as claimed in claim 1 or 2, characterized in that the surface
(17) of the steps (13, 13', ...) facing the in-coupling edge surface (4) comprises a specular
reflector (31) at a side facing away from the in-coupling edge surface (4).

5. A lighting system as claimed in claim 1 or 2, characterized in that the steps (13, 13', ...) comprise a diffuser (32) at a side facing away from the light-emitting panel (1) while maintaining an air gap (33) between the steps (13, 13', ...) and the diffuser (32).
- 5 6. A lighting system as claimed in claim 1 or 2, characterized in that the height h_{st} of a step (13, 13', ...) is in the range $0.1 \leq h_{st} \leq 0.5$ mm.
7. A lighting system as claimed in claim 1 or 2, characterized in that the distance
10 d_{st} between two steps (13, 13', ...) is in the range $0.1 \leq d_{st} \leq 10$ mm.
8. A lighting system as claimed in claim 1 or 2, characterized in that the number of steps (13, 13', ...) is in the range from 25 to 100.
- 15 9. A lighting system as claimed in claim 1 or 2, characterized in that the length l_p of the first portion (12) as compared to the length l_{fw} of the front wall (2) is in the range $0.05 \leq l_p/l_{fw} \leq 0.6$.
10. A lighting system as claimed in claim 1 or 2, characterized in that the ratio of
20 the surface area S_{es} of the in-coupling edge surface (4) and the surface area S_w in the light-emitting panel (1) of the transition between the first portion (12) and the second portion (22) of the light-emitting panel (1) satisfies the relation $1 < S_w/S_{es} < 10$.
11. A lighting system as claimed in claim 2, characterized in that the ratio
25 $1.5 < S_w/S_{es} < 4$.
12. A lighting system as claimed in claim 1 or 2, characterized in that the front wall (2) is provided with a translucent diffuser (8).
- 30 13. A lighting system as claimed in claim 1 or 2, characterized in that the front wall (2) is provided with a light redirecting foil.

14. A lighting system as claimed in claim 1 or 2, characterized in that the light source (6, 6', ...) comprises at least one white LED or at least two light-emitting diodes with different light emission wavelengths.

5 15. A lighting system as claimed in claim 13, characterized in that each of the light-emitting diodes has a luminous flux of at least 5 lm.

16. A display device provided with a lighting system as claimed in claim 1 or 2.

10 17. A display device as claimed in claim 15, which display device comprises a liquid crystal display (50).

ABSTRACT:

(76)

A compact backlight system has a light-emitting panel (1) with a front wall (2), a rear wall (3) situated opposite thereto, and furthermore, between the front and the rear wall (2, 3), a translucent in-coupling edge surface (4) for coupling light into the light-emitting panel (1). A light source (6, 6', ...) is associated with the in-coupling edge surface (4).

- 5 According to the invention, the rear wall (3) in a first portion (12) of the light-emitting panel (1) is provided with a multiplicity of steps (13, 13', ...), and a second portion (22) of the light-emitting panel (1) widens from the in-coupling edge surface (4) in a direction facing the first portion (12). Preferably, a surface (17) of the steps (13, 13', ...) facing the in-coupling edge surface (4) makes an angle $\beta_{av} \geq 5^\circ$ with respect to a normal on a bisecting plane (20)
- 10 bisecting the light-emitting panel (1).

Fig. 1A.

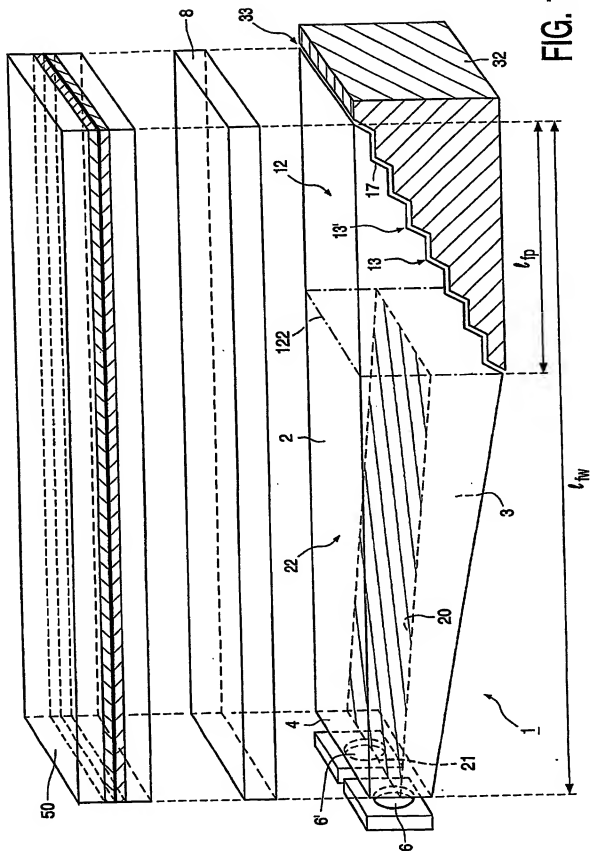
$\frac{1}{4}$ 

FIG. 1A

2/4

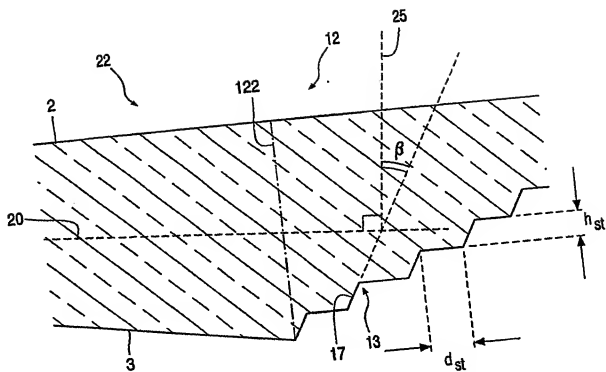


FIG. 1B

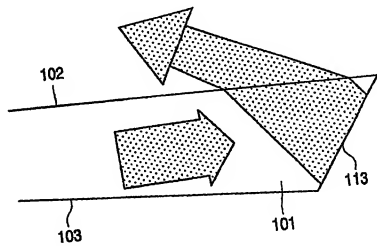


FIG. 2A

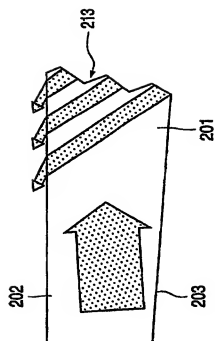


FIG. 2B

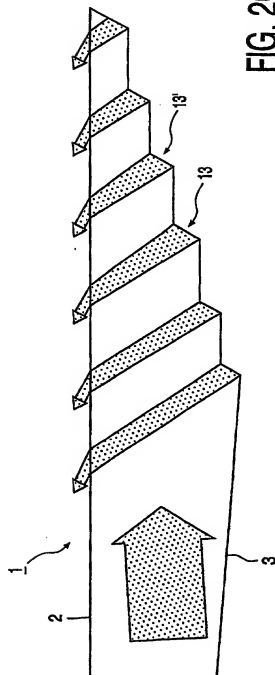


FIG. 2C